APPENDIX C

REGIONAL SETTING SUPPORTING INFORMATION

APPENDIX C
TABLE OF CONTENTS

APPENDIX C
LIST OF TABLES

APPENDIX C
LIST OF FIGURES

APPENDIX C: REGIONAL SETTING SUPPORTING INFORMATION

Climate

The climate within the study area is temperate and is favorable for many types of plants and animals. Generally, summers are warm and humid with winters moderately cold. Valleys can have lower temperatures than the surrounding hills when cooler heavier air drains to areas of lower elevations. Precipitation is fairly well distributed throughout the year. Seasonal temperatures, rainfall, snowfall, wind, and humidity differ from West Virginia, Kentucky, Tennessee and Virginia. Monthly temperature and precipitation data for each state within the study area are shown in Tables C-1 through C-4.

Table C-1
Monthly Temperature and Rainfall Data for the Kentucky Portion of the Study Area

Month	Approximate Range of Daily Maximum Temperature (°F)	Approximate Range of Daily Minimum Temperature (°F)	Approximate Monthly Rainfall (inches)
January	42-50	21-26	4-5
February	46-51	22-29	4
March	56-61	30-36	5
April	68-71	40-44	4
May	77-80	49-53	4
June	80-86	59-61	4
July	85-90	62-66	5
August	84-89	60-65	3-4
September	79-83	53-58	3-4
October	69-73	40-53	2
November	57-63	30-36	3-4
December	47-50	25-30	3-4

Table C-2
Monthly Temperature and Rainfall Data for the Tennessee Portion of the Study Area

Month	Approximate Range of Daily Maximum Temperature (°F)	Approximate Range of Daily Minimum Temperature (°F)	Approximate Monthly Rainfall (inches)
January	45-49	25-29	5
February	48-52	27-30	4-5
March	56-63	34-37	6
April	68-73	44-46	4-5
May	75-80	51-54	4-5
June	82-86	58-62	4-5
July	85-88	62-66	5
August	84-88	61-65	3-4
September	79-83	55-59	4
October	68-74	44-47	3
November	56-62	34-36	4
December	47-62	28-31	5-6

Table C-3
Monthly Temperature and Rainfall Data for the West Virginia Portion of the Study Area

Month	Approximate Range of Daily Maximum Temperature (°F)	Approximate Range of Daily Minimum Temperature (°F)	Approximate Monthly Rainfall (inches)
January	38-44	18-25	3-4
February	41-47	18-26	3
March	52-57	26-34	3-5
April	64-70	36-44	3-4
May	72-77	46-51	4
June	77-83	52-59	3-5
July	80-86	56-64	5-6
August	80-85	56-63	4-5
September	75-80	50-56	3-4
October	64-69	38-44	3
November	53-57	29-35	3
December	42-47	20-28	3-4

Table C-4
Monthly Temperature and Rainfall Data for the Virginia Portion of the Study Area

Month	Approximate Range of Daily Maximum Temperature (°F)	Approximate Range of Daily Minimum Temperature (°F)	Approximate Monthly Rainfall (inches)
January	37-44	17-22	3-4
February	40-49	19-25	3-4
March	50-59	28-34	4-5
April	59-69	35-42	3-4
May	68-77	44-50	4-5
June	75-84	52-58	4
July	78-87	56-63	5
August	77-86	55-62	3-4
September	71-81	48-56	3-4
October	61-70	36-43	2-3
November	51-60	29-35	3-4
December	41-49	21-27	3-4

Snowfall

The average amount of snowfall within the study area ranges from 7 to 50 inches, differing from West Virginia, Kentucky, Tennessee and Virginia. Information of a few select counties within the study area is provided for example purposes.

Nicholas County West Virginia has cold and snowy winters with an average yearly snowfall of approximately 50 inches. On average, approximately 34 days per year have at least one inch of snow on the ground. The average yearly snowfall in Braxton County, West Virginia, is approximately 29 inches. On the average, 15 days of the year have at least one inch of snow on the ground. The number of such days varies greatly from year to year. In Kanawah and Wyoming Counties, West Virginia, the average yearly snowfall is about 30 inches.

There is somewhat less snowfall in the Tennessee portion of the study area, than in the West Virginia portion. In Bledsoe, Fentress, Pickett, Anderson, and Cumberland Counties, average snowfall ranges from 7 to 20 inches per year.

Elliot, Bell, Harlan, Pike, Carter, Knox, Whitley, McCreary, Wayne, Jackson, Owsley, Powell, and Wolfe Counties, Kentucky. The average yearly snowfall is approximately 15 inches, but the ground is seldom covered with snow for more than a few days because of intermittent thaws. There is more than one inch of snow on the ground for approximately 4-8 days per year. During a normal year not more than six snowfalls are more than one inch deep.

The average annual snowfall in Bledsoe County, Tennessee, is 7 inches. It is seldom that more than one inch of snow is on the ground for a whole day.

Rainfall

Heavy rains, that occur at any time of the year, and severe thunderstorms in summer sometimes cause flash flooding, particularly in narrow valleys.

Approximate monthly rainfall averages for the Kentucky, Tennessee, and West Virginia portions of the study area can be seen in Tables C-1 through C-4. An approximate average of 43 to 50 inches of rain falls on the Kentucky portion of the study each year. Anywhere from 2 to 5 inches of rain can be expected in any given month of the year with the wettest month being July and the driest month being October. On average, approximately 90 to 97 days throughout the year will have 0.10 inches or more of precipitation in the Kentucky portion of the study area.

Approximately 52 to 55 inches of rain falls on the Tennessee portion of the study area in the average year. Anywhere from 3 to 6 inches of rain per month can be expected in this area with the wettest months being March and December and the driest month being October. Approximately 84 to 95 days throughout the year will experience greater than 0.10 inches of precipitation.

In the West Virginia portion of the study area, approximately 38 to 50 inches of rain occurs per year. Monthly rainfalls of 3 to 6 inches can also be expected in this area throughout the year. The wettest month tends to be July while the driest months are usually February, October, and November. Approximately 86 to 101 days throughout the year will experience greater that 0.10 inches of rain in the West Virginia portion of the study area.

In the Virginia portion of the study area, approximately 41 to 50 inches of rain occurs per year that is similar to the rest of the study area. Anywhere from 2 to 5 inches of rain can be expected in any given month of the year with the wettest months being March, May, and July and the driest month being October.

Supplemental Geology Information for the MTM/VF EIS Study Area

This appendix is provided for general reference on geologic considerations within the study area. Topics include environment of deposition, post-depositional deformation, chemical nature of overburden and potential for acid mine drainage formation, and detailed descriptions of coal-bearing rock units in Kentucky, Tennessee, Virginia, and West Virginia.

1. Environment of Deposition

Coal seams were formed by the accumulation and burial of plant material to form peat, which the pressure of overlying sediments eventually converted into coal. The physical and chemical properties of the coal and associated sedimentary rocks are related directly to the depositional environment in which the peat beds accumulated, and to the structural stresses exerted on the peat beds during and after their deposition and burial.

The Appalachian Basin of the eastern United States was a site of sediment accumulation for most of the Paleozoic era, approximately 570 to 225 million years ago, during which two significant mountain-building events occurred along the eastern margin of the continent. The latter of these events, known as the Appalachian orogeny, occurred from about 320 to 220 million years ago, during the Pennsylvanian through mid-Triassic periods. The coal-bearing or carboniferous rocks of the Appalachian coalfields accumulated from sediments shed off these mountains from approximately 300 to 250 million years ago, primarily during the Pennsylvanian period. Table C-5 depicts these periods in relation to the geologic time scale.

Sediments eroded from the ancestral Appalachian mountains were transported by streams and rivers to the Appalachian Basin, where a large inland sea existed at the time. Numerous swamps, river deltas, tidal deltas, and back barrier marshes existed in the coastal area of the ancient inland sea. The thickness and lateral extent of the swamps were partially dependent on the topographic surface on which the swamp developed (Horne et al. 1978). The extent and duration of each swamp determined the regional extent and thickness of individual coal seams. Discrete depositional events lasting millions of years, coupled with local and regional uplift, folding, and erosion, produced numerous discontinuous seams. Influxes of coarse-grained clastic sediments, forming shaly partings and impure coals, are commonly found in the Basin coal seams. Stream channel migration within the shifting fluvial and deltaic drainage systems eroded part of the swamp deposits. Other ancient stream channels were filled with fine to coarse-grained clastic sediments. These ancient areas of erosion and deposition in the swamp are represented by local thinning and lateral interruption of the seams. Differential compaction and slumping of the newly-deposited clastic sediments also formed irregularities in the underlying swamp deposits.

Table C-5 Geologic Time Scale

ERA	Period	EPOCH	Duration in Millions of Years (Approx.)	Millions of Years Ago (Approx.)
CENOZOIC	Quaternary	Recent		
	Tertiary	Pleistocene		1.8
		Pliocene	3.2	5.0
		Miocene	17.5	22.5
		Oligocene	15.0	37.5
		Eocene	16.0	53.5
		Paleocene	11.5	65
MESOZOIC	Cretaceous		71	136
	Jurassic		54-59	190-195
	Triassic		30-35	225
PALEOZOIC	Permian		55	280
	Pennsylvanian		40	320
	Mississippian		25	345
	Devonian		50	395
	Silurian		35-45	430-440
	Ordovician		60-70	500
	Cambrian		70	570
Precambrian				

The thickness, continuity, lateral extent, and quality of the coal seams in the study area relates directly to the depositional environment of each swamp and the depositional environment of the sediments that accumulated on top of the peat that was transformed into coal (Horne et al. 1978). The heating and compaction produced by the depth and duration of burial of the swamp deposits also affect the quality of the coal seam and overlying material.

The acid-forming, iron disulfide minerals known as pyrite and marcasite, and various trace elements, occur chiefly in depositional environments that are associated with slowly subsiding delta plains and back bays. Low concentrations of the acid forming iron disulfide minerals and trace elements occur in areas where sporadic but rapid subsidence of the coal-producing lower and upper delta plain, and back bay depositional environments.

2. Post-Depositional Deformation

The Appalachian orogeny lasted into the Triassic period, with mountain building and deformation continuing as the North American and African continents were driven together by tectonic forces. During the latter stages of the orogeny, the eastern portion of the Appalachian Basin was strongly deformed into tight fold structures, which later erosion would carve into the Valley and Ridge Province. At the Allegheny Front, the amplitude of folding abruptly diminishes, much as wrinkles in a tablecloth pushed by hand. Forces from the continental collision did propagate beyond the Allegheny Front to form low-amplitude anticlines and synclines with fold axes oriented in a general northeast to southwest direction.

With regards to coal mining, this deformational event divided the Appalachian coalfields between the steeply-dipping strata of the Valley and Ridge Province and the shallowly-dipping Appalachian Plateau Province. Regional metamorphism in the eastern part of the Valley and Ridge Province converted the coal deposits into anthracite, and the steep dips of the strata favored underground mining methods. Erosion of higher strata also removed the coal seams from many areas in this province where they had originally been deposited, generally limiting the extent of mining activities to several remnant deposits in large anticlines. West of the Allegheny Front, the coal was not metamorphosed, and the lesser degree of uplift from folding allowed much of the original coal to remain after erosion. The shallower dip of the low amplitude folds better permits use of surface mining methods and is also more efficient for underground methods. The combination of the two factors has allowed development of widespread surface and underground coal mining in the Appalachian Plateau Province. Fracturing of overburden rocks from folding stresses may also lower in this area, providing better roof support control in underground mining applications.

3. Toxic Overburden and Acid Mine Drainage Formation

Pyrite is a sulfide mineral formed in the reducing environments commonly associated with Bituminous coal fields. Coal mine drainage is produced by the oxidation of pyrite in an aqueous environment that dissociates the iron and sulfur found in the pyrite (FeS_2). Pyrite is found in several forms with end members consisting of globular framboidal to euhedral crystalline. A direct relationship exists between surface area and reactivity of the various forms of pyrite, with larger surface are (i.e. smaller particles) being more reactive (Caruccio, 1970). As such framboidal forms of pyrite tend to have greater surface area therefore possesses greater theoretical reactivity than other forms of pyrite.

The oxidation of the pyrite in the coal seam and overburden begins with the removal of the coal, exposing the pyrite to oxygen. Rose and Cravotta (Brady et al, 1999) summarized the stages of pyrite oxidation by the following stoichiometric reaction (1):

$$\mathbf{FeS_2\ (s) + 3.75\ O_2 + 3.5\ H_2O = Fe(OH)_3(s) + 2\ SO_4^{2-} + 4\ H^+ + heat} \qquad \mathbf{(1)}$$

In the above reaction, the reactants are shown on the left side of the equation as solid pyrite, water and oxygen while the products are located on the right side listed as ferric hydroxide, sulfate, hydrogen ions and heat.

Alkaline mine drainage can be produced when acidic mine pools come in contact with alkaline overburden and/or alkaline recharge migrates into the mine void. This water can contain significant quantities of carbonate or bicarbonate that have dissolved along the flow path. The initial reaction (2) between calcite, in limestone, and acidic water is:

$$\mathbf{CaCO_3 + 2H^+ = Ca^{2+} + H_2CO_3(aq)} \qquad \textbf{(2)}$$

As further neutralization continues, the reaction (3), for pH values above 6.3 can be given as (Cravotta et al, 1990):

$$\mathbf{FeS_2 + 4CaCO_3 + 3.75\ O_2 + 3.5\ H_2O = Fe(OH)_3 + 2\ SO_4^{2-} + 4\ Ca^{2+} + 4\ HCO_3^-} \qquad \textbf{(3)}$$

This reaction will produce alkaline mine drainage with circumneutral pH, alkalinity greater than acidity, high sulfate and calcium concentrations and iron hydroxide as a precipitate. Rose and Cravotta also point out that carbonate dissolution and production of alkalinity are independent of saturation conditions, significant reaction rates can occur under saturated and unsaturated conditions.

Toxic overburden also may contain elements that are poisonous to plants and animals, acid producing, or both. Excessive amounts of sodium, salt, sulfur, copper, nickel and other trace elements in the water or the soil derived from mined overburden have a detrimental effect on plants and may hinder revegetation (Torrey 1978). Arsenic, boron, and selenium are other elements that may be present in overburden. Acidic material or material with the potential of becoming acidic upon oxidation (pH 4.0 or less; chiefly the minerals pyrite or marcasite) has the capability to cause water pollution by chemical reaction resulting in increased concentrations of dissolved iron and other metals at low pH.

As a general rule, the southern coal seams and associated overburden contain less sulfur concentrations than northern coal seams, most notably from mid West Virginia northward. Southern coal measures also have a dearth of alkaline (carbonate) material resulting in low buffering capacities of the overburden. In these areas, threshold OBA values are vitally important because small amounts of pyrite can lead to formation of AMD due to the paucity of alkaline material. In these instances, alkaline addition into the backfill is a common reclamation practice.

Acid mine drainage is a potential problem anywhere in the Appalachian Basin because alkaline overburden with high buffering capacity is scarce and discontinuous, and unweathered zones in the massive sandstones overlying the coal seams are frequently pyritic with a high potential for acid production. In the northern coalfield, mining practices as well as local variability of the thickness and lateral extent of limestone-rich materials affect mine drainage quality. The variability in acid drainage problems may be compounded when more than one coal seam is mined or the coal seam splits into two or more benches locally.

4. Coal-Bearing Geologic Formations in the Study Area

The following narrative sections present information on the coal-bearing geologic formations for each of the four states within the study area. Refer to Table C-6 for a stratigraphic correlation chart that provides both a geologic timescale and correlations of units across state boundaries.

a. Kentucky

One to four coal seams are present in with the northern coal basin area of Kentucky and increase to as many as 15 seams within the southern part of the basin. The coal seams are thin and discontinuous for the most part, with only one to three coals being extensively mined. (Kiesler, 1983, Leist, 1982, and Quinones, 1981). Refer to Table C-7 for a list of coal beds found within the Kentucky coal basin.

Upper Mississippian Rock Units

The Upper Mississippian rock units of along the northwestern edge of the Kentucky coalfields include the Newman Limestone of the Pennington Group to the northeast. To the southwest the coalfields are also bordered by Pennington Group rocks but include the Bangor, Kidder, and Monteagle Limestones. Along the southeastern boundary of the coalfields the Upper Mississippian rocks also include the Newman limestone, two shale units, the Fort Payne Chert, and the Berea Sandstone. Upper Mississippian rock units along the southeastern coalfield boundaries are exposed along the Pine Mountain Overthrust Belt (Noger, 1988).

Table C-6
Stratigraphic Correlation Chart of the Appalachian Plateau Province *

<table>
<tr><th>Geologic System</th><th>West Virginia</th><th>Virginia</th><th>Kentucky</th><th>Tennessee</th></tr>
<tr><td>Quaternary</td><td>Recent Valley Alluvium</td><td rowspan="5">Recent Valley Alluvium</td><td rowspan="2">Recent Valley Alluvium</td><td rowspan="4">Recent Valley Alluvium</td></tr>
<tr><td>Permian</td><td>Dunkard Group</td></tr>
<tr><td rowspan="2">Upper Pennsylvanian</td><td>Monongahela Group</td><td>Monongahela Group</td></tr>
<tr><td>Conemaugh Fm.</td><td>Conemaugh Fm.</td></tr>
<tr><td>Middle Pennsylvanian</td><td rowspan="2">Allegheny Group</td><td rowspan="3">Breathitt Formation</td><td>Cross Mt. Fm.
Vowell Mt. Fm.
Redoak Mt. Fm.
Graves Gap Fm.
Indian Bluff Fm.</td></tr>
<tr><td rowspan="2">Lower to Middle Pennsylvanian</td><td rowspan="2">Harlan Formation</td><td rowspan="2">Slatestone Formation
Crooked Fork Group</td></tr>
<tr><td rowspan="3">Pottsville Group

Formerly Kanawha
New River
Pocahontas
Formations</td></tr>
<tr><td rowspan="2">Lower Pennsylvanian</td><td rowspan="2">Wise Fm.
Gladeville SS
Norton Fm.
Lee Fm.</td><td rowspan="2">Lee Formation</td><td>Crab Orchard Mountains Group</td></tr>
<tr><td>Gizzard Group</td></tr>
<tr><td>Upper Mississippian</td><td>Mauch Chunk Group</td><td>Pennington Fm.</td><td>Pennington Fm.</td><td>Pennington Fm</td></tr>
<tr><td>Upper to Middle Mississippian</td><td>Greenbrier Limestone</td><td>Greenbrier Limestone</td><td>Newman Limestone</td><td>Newman Limestone</td></tr>
</table>

*Developed from USGS HA 730-L and HA 730-K, Harlow (1993), Cardwell (1968), and Rader (1993).

Pennsylvanian Lee Formation

The Lee formation is characterized by massive orthquartizite sandstone beds with lenses of conglomerate; sandstone comprises up to 80 percent of the formation. The formation in Eastern Kentucky is divided into the upper Corbin Sandstone Member and lower Rockcastle Sandstone Member. Sandstone beds can intertongue or grade into shale beds which range from 20-40 feet Interbeds of carbonaceous shale, siltstone, coal (included in the formation) are most common in upper part of the formation. Lower members in places intertongue with Upper Mississippian rocks (Leist, 1982). The Lee Formation. typically outcrops in deeply eroded stream valleys and along structural highs of the Eastern Kentucky coal basin.

The Lee Formation, along with under- and overlying beds, has a gentle southeasterly dip and thickens to the southeast towards the Cumberland Mountain Overthrust block (Quinones, 1981). The Lee Formation is mostly exposed along the northwestern boundary of the KY coal basin and ranges in thickness from about 500 feet in northeastern KY to about 1,500 feet in along the southern margins of the KY coalfields (Kiesler, 1983, Leist, 1982, and Quinones, 1981). Thin outcrop patterns also occur along the southeast margin of the KY coalfields along the Cumberland Mountain Overthrust block (Noger, 1988).

Pennsylvanian Breathitt Formation

Within the eastern Kentucky coal basin, the Breathitt Formation rocks are divided into upper, middle, and lower members and have the most extensive surface coverage of any formation in the basin, approaching approximately 75 percent. The Breathitt Group rocks are comprised of siltstone, sandstone, shale, coal, underclay, ironstone, but very little limestone aside from the Magoffin Member limestone and calcareous shale, which is widespread within the middle portion of the formation. Sandstone units usually range in thickness from 30 to 120 feet and are less competent than the sandstones of the underlying Lee Group. The unit reaches its maximum thickness along the southeastern edge of the coal basin, achieving thickness of about 3000 feet. Basal portions of the Breathitt Formation intertongue with the underlying Lee Formation (Kiesler, 1983, Leist, 1982, Quinones, 1981, and Noger, 1988).

The Breathitt Group rocks contain the majority of the mineable coals within the Basin, and number upwards of 21 to 30 coals (refer to Table C-7) depending upon the location within the Eastern Kentucky Coal Basin. Thicknesses and extents of coal units are variable. Unit thickness ranges from 6 to 100 inches. The thickest beds tend to be elongate in a northeasterly direction within the basin.

Pennsylvania Conemaugh Group

In northeastern Kentucky, the Conemaugh Group includes shale, siltstone, variegated sandstone, and a few thin coals (Kiesler, 1983). Included in ascending order are the Brush Creek Coal (Princess No. 10), Brush Creek Limestone, and Ames Limestone. The Conemaugh Group ranges in thickness from 430-460 feet (Noger, 1988).

Pennsylvania Monongahela Group

The Monongahela Group is comprised of shale and sandstone and is described as being at least 140 feet thick in northeastern Kentucky (Noger, 1988). No reference to the presence of any coals is made within the Kentucky Geologic Map (Noger, 1988).

Pennsylvania Conemaugh/Monongahela Groups Undifferentiated

W.E. Price, et.al. (1962) describe the undifferentiated Conemaugh/Monongahela Group as containing variegated siltstones and claystones with massive sandstones in the lower part. Also included are a few thin coals and limestones (Price, 1962). Price (1962) describes three sandstone members in ascending order: the Mahoning Member (maximum 100 feet thick), the Buffalo Member (average 45 feet), and the Morgantown Member (average 50 feet thick).

Table C-7
Correlation Chart of Major Coal Beds and Coal Zones and Other Key Beds of the Pennsylvanian of Eastern Kentucky (Modified from Rice and Others, 1979)

		North of Pine Mountain Fault			Along and South of Pine Mountain Fault		
		North	East	South			
Conemaugh and Monongahela Formations			Removed by erosion	Removed by erosion	Remove by erosion		
		Ames Limestone Member					
		Brush Creek Limestone Member					
		Brush Creek coal bed					
	Upper part of Breathitt Formation	Upper Freeport coal bed					
		Princess No. 8 coal bed					
		Princess No. 7 coal bed					
		Princess No. 6 coal bed					
		Obryan (Vanport) Limestone Member[1]					
		Flint Ridge Flint of Morse (1931)					
		Princess No. 5 (Skyline) coal zone	Richardson coal zone	Knob coal zone			
Lee and Breathitt Formations	Middle part of Breathitt Formation	Princess No. 4 coal bed	Broad coal zone	Broas coal zone			
				Stoney Fork Member			
			Hindman coal bed	Hazard No. 9 coal zone			
		Princess No. 3 (Mudseam) coal bed	Peach Orchard coal zone	Francis coal zone		Middle part	Breathitt Formation
				Big Wheel coal bed	High Splint Coal Bed		
			Hazard coal zone	Braden Mountain Coal Bed	Red Springs coal bed		
			Haddix coal zone	Red Ash coal bed	Low Splint coal bed		
		Magoffin Member	Magoffin Member	Magoffin Member	Magoffin Member		
	Lee Formation and lower part of Breathitt Formations	Taylor coal bed	Taylor (Sharp) coal bed	Copland (Sharp) coal bed	Limestone coal bed	Lower part	
		Hamlin coal zone	Hamlin coal zone	Beech Grove coal bed	Pardee coal bed		
				Hatfield coal bed	Hignite (Smith) coal bed		
		Fire Clay Rider coal bed	Fire Clay-Whitesburg coal zone	Big Mary coal bed			
		Fire Clay coal bed		Windrock coal bed	Wallins Creek coal bed		
		Little Fire Clay coal bed		Upper Pioneer coal bed			
		Whitesburg coal bed					
		Kendrick Shale Member	Kendrick Shale Member		Kendrick Shale Member		
		Cannel City coal bed	Amburgy coal zone	Lower Pioneer coal bed			
				Jordan coal bed	Poplar Lick (Creech) coal bed		
			Elkins Fork Shale of Morse (1931)				
		Tom Cooper (Van Lear) coal bed	Upper Elkhorn No. 3 coal bed	Elk Gap coal bed	Darby coal bed		
				Lick Fork coal bed	Kellioka (Taggart marker) coal bed		
		Grassy coal bed	Alma coal zone	Jelico coal zone	Collier coal bed		
					Harlan (Mingo) coal zone		
		Bruin coal bed	Lower Elkhorn coal bed	Blue Gem coal bed			
			Powellton coal zone	Little Blue Gem coal bed	Path Fork (Rich Mountain) coal bed		
		Betsie Shale Member	Betsie Shale Member	Betsie Shale Member	Betsie Shale Member		
		Zachariah coal bed	Clintwood (Matewan) coal bed	Lily (Manchester, River Gem, or Swamp Angel) coal bed	Hance (Bennetts Fork) coal bed		
		Corbin Sandstone Member of Lee Formation	Cedar coal bed	Corbin Sandstone Member of Lee Formation			
		Mine Fork coal bed	Little Cedar coal bed	Gray Hawk coal bed	Mason (Murray) coal bed		
			Splash Dam coal bed	Beattyville coal bed	Splitseam coal bed		
		Warm Fork coal bed		Barren Fork coal bed	Clear Fork (Rex) coal bed		
		Olive Hill Clay bed of Crider (1913)	Lower Banner coal bed	Rockcastle Sandstone Member of Lee Formation			
			Lee Formation (undivided)		Naese coal bed		
						Lee Formation	
				Beaver Creek coal bed	Tunnel coal bed		
				Stearns No. 1 ½ coal bed			
				Stearns No. 1 coal bed			
				Livingston Conglomerate Member of Lee Formation			
					Cumberland Gap coal bed		

[1]Revised stratigraphic nomenclature (Rice and others, in press)

b. Tennessee

The geologic formations of Upper Mississippian and Pennsylvanian age in Tennessee are described in ascending order in the sections that follow. Table C-8 depicts Eastern Tennessee coalbeds.

Upper Mississippian Rocks

Throughout the Eastern Tennessee coalfields, the Upper Mississippian Pennington Formation separates the Pennsylvanian-aged coals and associated rocks from the underlying Mississippian aged carbonates and related rocks. The Pennington Formation is a transitional unit and ranges in thickness from 100 to 700 feet from west to east. The formation is composed of shale (highly variegated and distinctive to the east), fine-grained sandstone, and conglomerates which grade downwards to limestones/carbonates, and has a persistent dolomite at its base. The Pennington Formation underlies most all the Cumberland Plateau and outcrops along its western and eastern margins (Gaydos, 1982 and Hardeman, 1966).

Pennsylvanian Rocks

The Pennsylvanian-aged rocks cap the extensive uplands of the Cumberland Plateau and contain the coals of the Eastern Coal Province of Tennessee. Within the northern portion of the coal province, or coalfields, these rocks range in thickness from 600 to 3,000 feet from east to west (Gaydos, 1982). Within the southern portion of the province, Pennsylvania-aged rocks range in thickness from approximately 200 to 1,000 feet from west to east (Hollyday, 1983 and May, 1983). The rocks are comprised of cyclical sequences of shale and conglomerate with lesser amounts of siltstone and coal to the west and cyclical sequences of sandstone, siltstone, shale, coal, underclay, and conglomerate to the east. Older Pennsylvanian rocks underlie the near surface to the west, while younger rocks underlie the near surface to the east, due to the predominant dip and thickening of rock units towards the east. The following narrative summarizes the major Pennsylvanian-aged rock units of the Cumberland Plateau coalfields.

Lower Pennsylvanian Gizzard Group

Shale, siltstone, sandstone, and conglomerate comprise the Gizzard Group. This unit extends from the base of the overlying Sewanee Conglomerate to the top of the Pennington Formation. Thickness ranges from 0 to 520 feet (Hardeman, 1966). The Warren Point sandstone is a significant unit in this group averaging 100 feet in thickness (Brahana, 1986). This unit exists at ground surface primarily in the extreme southern portion of the coalfield (Hardeman, 1966).

Lower Pennsylvanian Crab Orchard Mountain Group

This group of associated rocks is comprised of primarily conglomerate, sandstone, siltstone, shale, and coal. The unit extends from the Rockcastle Conglomerate to the base of the Sewanee Conglomerate. Thickness ranges from 200 to 950 feet (Hardeman, 1966). In ascending order, it includes the Sewanee, Lantana, and Morgan Springs coals (Hardeman, 1966 and Hollyday, 1983). Three major sandstone units occur in the group which, in ascending order, include the Sewanee, Newton, and Rockcastle (Brahana, 1986). This unit exists at the ground surface over extensive portions of the southern to central coalfields.

Middle Pennsylvanian Crooked Fork Group

The Crooked Fork Group consists primarily of shale, sandstone, conglomerate, siltstone, and coal and extends from the Poplar Creek Coal down to the top of the Rockcastle Conglomerate. Group thickness ranges from 320 to 455 feet (Hardeman, 1966). This unit has a somewhat limited coverage at ground surface and is present within the north-central and northern portions of the basin (Hardeman, 1966). Major coals include, in ascending order, the Rex, Hooper, and Poplar Creek (Hardeman, 1966). Sandstone units in this group and those overlying are generally much thinner and less laterally persistent versus those in the underlying units discussed above.

Middle Pennsylvanian Formations

These units occur only within the northeastern portion of the plateau coalfields and overlie the preceding formations. Six formations comprise the Middle Pennsylvanian in the Tennessee coalfields and include the following in ascending order (Hardeman, 1966):

<u>Slatestone Formation</u> – Shale, sandstone, siltstone, and several important coals including the Jellico and Poplar Creek – 500 to 720 feet thick.

<u>Indian Bluff Formation</u> – Shale, sandstone, siltstone and thin coals; includes the Pioneer Sandstone at top – 150 to 475 feet thick.

<u>Graves Gap Formation</u> – Shale, sandstone, siltstone, and coal; includes the Windrock coal – 275 to 385 feet.

<u>Redoak Mountain Formation</u> – Shale, sandstone, siltstone, and several important coals including the Pewee coal – 340 to 420 feet.

<u>Vowell Mountain Formation</u> – Shale, sandstone, siltstone, and coal; includes the Frozen Head Sandstone Member – 230 to 375 feet.

<u>Cross Mountain Formation</u> – Shale interbedded with sandstone, siltstone, and thin coal beds – maximum thickness is 550 feet.

Coal units within the Eastern Coal Province of Tennessee are difficult to correlate regionally (May, 1983). The important coals in northern Tennessee are the Upper Pennsylvanian Pewee, Big Mary, and Jellico coals of Upper Pennsylvanian age, the Coal Creek of Upper Pennsylvanian age, and the Sewanee of Lower Middle Pennsylvanian age (Gaydos, 1982). In the west-central portion of the coalfields, the important coals include the Richland and overlying Sewanee coals found within the Crab Orchard Mt. Group of Lower Pennsylvanian age (May, 1981 and Hardeman, 1966).

The primary coals within the east-central portion of the basin are the Big Mary, Rock Springs, and Coal Creek coals, whose position within the Pennsylvanian sequence is not specified (Gaydos, 1982). Possibly these coals have been renamed. Within the southern section of the coalfields, the major coals include (in ascending order) the Bon Air within the Lower Pennsylvanian Gizzard Group, the Richland, Sewanee, Lantana, and Morgan Springs located within the Lower to Middle Pennsylvania Crab Orchard Mt. Formation (Hollyday, 1983).

Table C-8
Eastern Tennessee Coal Beds

Geologic System	Formation/Group	Coal Bed*
Middle Pennsylvanian	Cross Mountain Formation	(thin coals)
	Vowell Mountain Formation	(various coals)
	Redoak Mountain Formation	Pewee
	Graves Gap Formation	Windrock
	Indian Bluff Formation	(thin coals)
	Slatestone Formation	Jellico
	Crooked Fork Group	Poplar Creek Hooper Rex
Lower Pennsylvanian	Crab Orchard Mountain Group	Morgan Springs (underlies Rockcastle Conglomerate) Lantana (overlies Newton Sandstone) Sewanee Richland (overlies the Sewanee Conglomerate)
	Gizzard Group	Wilder Bon Air (underlies Warren Point Sandstone) White Oak Sale Creek

(Taken from USGS Water-Resources Investigations Open File Report 82-679 (1983), Figure 2.2-2 and Geologic Map of Tennessee, Tennessee Department of Conservation, Division of Geology, 1966, East-Central Sheet)
* This list is not necessarily a complete list; it is based upon listed references.

c. Virginia

The geologic formations of Upper Mississippian and Pennsylvanian age in Virginia are described in ascending order in the sections that follow. The nomenclature used for these units can be found in Table C-9.

Upper Mississippian Rocks

The Upper Mississippian Rocks within the Southwestern Virginia coalfields consist primarily of the Pennington Group. This group consists of shale, sandstone, mudstone, conglomerate, siltstone, and minor limestone and coal. The shale, siltstone, and mudstone occur in variegated colors of gray, black, and red (Harlow, 1993). The top of the Pennington Group intertongues in places with the overlying Pennsylvanian Lee Formation. The Pennington ranges in thickness from 235 feet in the southwest to 2,355 feet to the northeast in Tazewell County.

Pennsylvanian Rocks

The Pennsylvanian-aged rocks of the southwestern Virginia coalfields in ascending order include the Lee and Norton Formations, the Gladeville Sandstone, and the Wise Formation over the majority of the coalfields except the northeastern corner (eastern Buchanan and western Tazewell Counties) where the laterally-equivalent Pocahontas, New River, and Kanawha Formations overlie Upper Mississippian rocks. The Upper Mississippian and overlying Pennsylvanian rock units of the Southwestern Virginia coalfields are summarized in ascending order below.

Lower Pennsylvanian Lee Formation

The Lee Formation consists of quartzarenite, conglomerate, sandstone, shale, siltstone, and coal. The Lee Formation ranges in thickness from zero feet in Buchanan County to 1680 feet in Lee County (Rader, 1993). The Lee Formation is dominated by three quartz-rich sandstone members that form steep cliffs and ridges (Harlow, 1993). In ascending order these members include the Middlesboro Member and the Bee Rock Sandstone. The Middlesboro Member overlies Upper Mississippian rocks and is composed of two tongues of clean, light gray quartzose sandstone that thin to the southeast. The lower tongue has a maximum thickness of 400 feet, the upper tongue being thinner at approximately 125 feet (Harlow, 1993). The Bee Rock Sandstone Member is a 100-ft thick unit of quarztose, conglomeratic sandstone (Harlow, 1993). Per Harlow (1993) the base of the Norton Formation is defined as the top of the uppermost quartzarenite rock unit of the Lee Formation and from northwest to southeast this boundary is displaced downward as the quartzarenite bodies pinch out, such that the boundary then becomes the top of the Naese Sandstone Member, the Bee Rock Sandstone Member, and finally the upper or lower part of the Middlesboro Member. Refer to Table V.A.2-5 below for coal beds known to occur in the Lee Formation and overlying formations.

Pocahontas Formation

The Pocahontas Formation is laterally equivalent to the Lee Formation and underlies the New Ricer Formation in the northeastern coalfield area (Rader, 1993). The unit thins to the northwest and is fine- to medium-grained micaceous, feldspathic sandstone interbedded with siltstone, coal, and underclay (Harlow, 1993). Sandstone comprises 70 percent of the formation (Rader, 1993). The deep coal seams of the Pocahontas Formation are generally thicker than the coal of the overlying Norton and Wise formations (Harlow, 1993). The Pocahontas Formation is also known for its thick, low-sulfur coal seams (Harlow, 1993). The unit ranges in thickness from zero to 970 feet achieving maximum thickness in Tazewell County (Rader, 1993).

Lower Pennsylvanian Norton Formation

The Norton Formation lies just below ground surface over most of Dickenson and Buchanan Counties. The Norton Formation overlies the Lee Formation and underlies the Wise Formation and Gladeville Sandstone within the southwestern Virginia Coal field region. The unit consists of siltstone and shale, and some sandstone, coal, and underclay. The siltstone and shale are gray to dark gray and thinly laminated and the sandstone is fine to medium grained and weakly cemented. To the northwest the average thickness ranges from 750-800 feet; to the southeast the formation is up to 1,300 feet thick (Harlow, 1993). Per the Virginia Geologic Map (1993), the formation thickens from northwest to southeast across the coalfields from 500 to 2,480 feet.

Per Harlow, the base of the Norton Formation is defined as the top of the uppermost quartzarenite of the Lee Formation. From northwest to southeast across the coalfield, this lower boundary is displaced downward as the Lee Formation quartzarenite bodies pinch out such that the lower boundary transitions from the top of the Naese Sandstone Member, the Bee Rock Sandstone Member, the upper part of the Middlesboro Member to the lower part of the Middlesboro Member (Harlow, 1993). The Norton Formation contains nine mineable coal seams, eight of which were evaluated for hydraulic conductivity by G.E. Harlow and include the Kennedy, Bearwallow, Big Fork, Lower Banner, Upper Banner, Splashdam, Hagy, and the Norton (Harlow, 1993).

Lower Pennsylvanian New River Formation

The New River Formation of Lower Pennsylvanian age is a coal-bearing sequence of sandstone, siltstone, and shale. Lithologically similar to the Pocahontas Formation except for the presence of coarse-grained quartzarenite and conglomerate sandstone that grades laterally into the Middlesboro Member of the Lee Formation. The New River Formation conformably overlies the Pocahontas Formation and is known for numerous thick, low-sulfur coal seams. These seams thin to the northwest across the basin where the New River and Pocahontas intertongue with the Lee Formation. Some of the coal seams included within the formation are the Lower Seaboard, Upper Seaboard, Castle, Tiller, and Jawbone (Harlow, 1993). Formation thickness is estimated to range from 1,380 to 1,925 feet from southwest to northeast.

Lower Pennsylvanian Gladeville Sandstone and Wise Formation

The Gladeville is a resistant quartzose sandstone and conglomerate that conformably overlies the Norton Formation. In southern sections of Wise and Dickenson Counties it forms numerous ridges and low plateaus. The Gladeville thins and eventually is absent to the north and northeast (Harlow, 1993). This unit ranges in thickness from zero up to 65 feet (Rader, 1993). The Wise Formation is composed of composed of siltstone, sandstone, shale, limestone, coal, underclay, and two distinctive calcareous shale units. The formation includes several thick sandstone units, including the Clover Fork, Marcum Hollow, and Reynolds sandstone members. It conformably overlies the Gladeville Sandstone and reaches a thickness of 2,300 ft to the northwest, where it is capped by the Harlan Sandstone. The formation contains up to 18 coal seams including, in ascending order, the Dorchester, Lyons, Blair, Clintwood, Imboden, Kelly, Upper St. Charles, Wilson, Taggart Marker, and Low Splint (Harlow, 1993). Additional coals include the High Splint at the top of the formation and the Williamson (Rader, 1993).

Lower Pennsylvanian Kanawha Formation

The Kanawha Formation consists primarily of sandstone, siltstone, shale, coal, and underclay. The upper sandstone beds are locally congolomeratic, lenticular, and thickly to massively bedded. The base of formation is conformable and placed at the bottom of the Kennedy Coal that overlies the McClure Sandstone member of the New River Formation. The Kanawha is equivalent to the Wise Formation and upper part of the Norton Formation and is approximately 550+ feet thick. The upper part of the formation is eroded within the Virginia coalfields.

Lower to Middle Pennsylvanian Harlan Formation

The Harlan Formation consists of sandstone, siltstone, shale, and coal. The sandstone is moderately resistant and comprises approximately 48 percent of the formation. The formations contain 22 discontinuous coal beds, and the base is defined as the top of High Splint Coal. The formation is up to 650 feet in thickness (Rader, 1993).

Table C-9
Southwestern Virginia Coalbeds

<table>
<tr><th>Geologic System</th><th>Formation/ Group</th><th colspan="2">Coal Bed Name</th><th>Formation/ Group</th></tr>
<tr><td>Lower to Middle Penn.</td><td>Harlan Formation</td><td>22 discontinuous coals</td><td></td><td></td></tr>
<tr><td rowspan="6">Lower Pennsylvanian</td><td>Wise Formation and

Gladeville Sandstone</td><td>High Splint (top)
Low Splint
Taggart Marker
Wilson
Upper St. Charles
Kelly
Imboden
Clintwood
Blair
Lyons
[Williams-pos.?]
[Philips-pos.?]
[Numerous others]
Dorchester (base)</td><td rowspan="2">[Coal present but no specific data located]

Kennedy (base)</td><td rowspan="2">Kanawha Fm.
(top part eroded)</td></tr>
<tr><td rowspan="2">Norton Fm.</td><td rowspan="2">Norton
Hagy
Splashdam
Upper Banner
Lower Banner
Big Fork
Bearwallow
Kennedy</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Norton Fm.</td><td></td><td>Jawbone
Tiller
Castle
Upper Seaboard
Lower Seaboard</td><td>New River Fm.</td></tr>
<tr><td rowspan="2">Lee Fm.</td><td rowspan="2">coal – up to 6 seams including:
Raven
Jawbone
Tiller</td><td></td><td></td></tr>
<tr><td>Coal present in seams thicker than those of Norton and Wise Fm.</td><td>Pocahontas Fm.</td></tr>
<tr><td>Upper Miss.</td><td colspan="4">Pennington Group</td></tr>
</table>

Source: Rader, 1993 and Harlow, 1993.

d. West Virginia

The geologic formations of Upper Mississippian and Pennsylvanian age in West Virginia are described in ascending order in the section that follows. Table C-10 summarizes the significant coal beds found within the Appalachian Plateau coalfields of southern West Virginia. Within the following narrative, the older formation name usage for the Lower Pennsylvanian-aged rocks in West Virginia is used here (Pocahontas, New River, and Kanawha Formations in ascending order) rather than Pottsville Group terminology which is the current usage as shown in Table C-6.

Upper Mississippian

The pre-Pottsville rocks include the Upper Mississippian-age shales and sandstones of the Mauch Chunk Group. These strata include by definition no coal beds. The Mauch Chunk Group is of hydrogeologic interest as a source of domestic and agricultural water supplies (Friel et al. 1967).

Pocahontas Formation

The coalbeds of the Pocahontas Formation are interbedded with sandstones, shales, siltstones, and underclays. The sandstones are light gray, very fine to coarse grained, thin-bedded to massive, and crossbedded. They consist of 50 to 65 percent quartz with large proportions of white-weathering feldspar, mica flakes, and dark mineral grains. The shales are medium to dark gray, thinly laminated, and carbonaceous. Horizontally laminated or crossbedded, medium light gray siltstones and medium-gray clayey to silty underclays occur in thin beds throughout the Pocahontas Formation (Hadley 1968; Cardwell 1975).

New River Formation

The lithology of the New River Formation is nearly identical to that of the underlying Pocahontas Formation (Englund 1968; Cardwell et al. 1968). Sandstones of the New River Formation are locally thicker, more massive, and more conglomeratic or quartzose than those of the Pocahontas Formation. The sandstones are moderately resistant and overly broad upland areas in central and eastern Raleigh County (Hadley 1978).

Kanawha Formation

The light gray, very fine to medium-grained, crossbedded, sub-graywacke sandstones weather faster than the sandstones of the underlying New River Formation. Kanawha Formation sandstones consist of 50 to 65 percent quartz with feldspar, mica, rock fragments, and opaque mineral grains. The beds of shale and siltstone are medium to dark gray, laminated, and locally calcareous. Large argillaceous (impure) limestone deposits occur in ellipsoidal concretions or thin discontinuous calcareous (carbonate-rich) beds with marine fossils locally present (Englund 1968).

Allegheny Formation

The Allegheny Formation consists of cyclical sequences of sandstone, siltstone, shale, limestone, coal, and underclay. (Englund 1968; Cardwell 1975).

Conemaugh Group

These strata comprise mostly non-marine cycles of red and gray shale, siltstone, sandstone, and thin beds of limestone and coal. The Conemaugh Group extends from the top of the Upper Freeport Coal to the base of the Pittsburgh Coal. Outcrops of the Conemaugh Group generally are limited to ridgetops and isolated peaks or small plateau areas.

Monongahela Group

The Monongahela Group is composed of non-marine red and gray shale, siltstone, sandstone, limestone, and coal. The Monongahela Group extends from the base of the Pittsburgh Coal to the top of the Waynesburg Coal. The thickness of the Monongahela Group in the Basin ranges from less than 100 feet to more than 400 feet.

Dunkard Group

Outcrops of these rocks are limited to the crests of ridges. The Dunkard Group extends from the top of the Waynesburg Coal upward to the bottom of the Upper Proctor Sandstone. The maximum thickness of the Group in West Virginia is nearly 1,200 feet. The Dunkard Group consists of cyclic sequences of non-marine red and gray shale, siltstone, sandstone, limestone, and coal.

Table C-10
Unified Stratigraphic Columns - West Virginia (Lotz 1970, USBM 1977)

Age	Rock Unit	Name	Local Names
PERMIAN	Dunkard Group	Nineveh	
		Hostetter	
		Fish Creek	
		Dunkard	
		Jollytown	
		Hundred	
		Washington "A"	
		Washington	
		Little Washington	
		Waynesburg "B"	
		Waynesburg "A"	
	Monongahela Group	Waynesburg	Fairview, Mt. Morris
		Little Waynesburg	
		Uniontown	
		Lower Uniontown	
		Sewickley	Mapletown, Tyron, Tyson
		Redstone	Pomeroy
		Pittsburgh	Big Vein, Pittsburgh No. 8 Raymond, Raymond City, Sally Malone
PENNSYLVANIAN	Conemaugh Group	Morgantown	
		Little Pittsburgh	
		Second Little Pittsburgh	
		Franklin Rider	
		Little Clarksburg	Dirty Nine-foot, Franklin
		Normantown	
		Lower Hoffman	
		Upper Clarysville	
		Lower Clarysville	
		Wellersburg Rider	
		Wellersburg	
		Barton Rider	
		Elk Lick	Barton, Four-foot
	Conemaugh Group	West Milford	
		Federal Hill	

Table C-10
Unified Stratigraphic Columns - West Virginia (Lotz 1970, USBM 1977)

Age	Rock Unit	Name	Local Names
		Duquesne	
		Harlem	Crinoidal, Friendsville
		Upper Bakerstown	
		Bakerstown	Thomas
		Brush Creek	Forked Seam
		Mahoning	Six-foot
PENNSYLVANIAN	Allegheny Group	Upper Freeport	Davis, Split-six
		Lower Freeport	"D" Block, Roger
		Upper Kittanning Rider	
		Upper Kittanning	
		Middle Kittanning	North Coalburg
		Lower Kittanning	No. 5 Block, Tioga
		Clarion	Little No. 5 Block
		Tionesta	
	Kanawha Group	Upper Mercer	Stockton "A"
		Stockton-Lewiston	Belmont, Lewiston, Lower Mercer, Stockton
		Coalburg	
		Little Coalburg	
		Buffalo Creek	
		Winifrede	Black Bank, Dorothy, Quakertown
		Lower Winifrede	
		Chilton (A)	
		Chilton Rider	
		Chilton	
		Little Chilton	
		Hernshaw	
		Dingess	
		Williamson Rider	
		Williamson	
		Cedar Grove	Island Creek, Marpleton, Red Jacket, Thacker

Groundwater Characterization

Surface coal mining can directly impact groundwater resources by altering the physical structure of aquifers overlying the coal seams being mined, replacing rock units of varying hydrologic properties with backfill spoil of a fairly heterogeneous nature. Placement of fills in hollows and valleys may change groundwater flow regimes as well by creating a groundwater storage medium where one did not previously exist. Recharge rates, groundwater elevations, and discharge patterns may all change within and around a mine site as a result. From a water quality standpoint, surface coal mining may expose acid-forming minerals in coal and overburden to accelerated reaction with air and water, resulting in acid mine drainage formation or elevated metals concentrations that may migrate into the groundwater system. Underground mining may have a lesser effect on overlying aquifers depending on its depth and overburden characteristics, but can still result in dewatering or changes in groundwater flow patterns, and is similarly susceptible to generation of acid mine drainage.

To provide background information to evaluate the potential effects of mining on groundwater quality and quantity, the following section describes the general characteristics of groundwater occurrence, quantity, quality, and related information for the Appalachian Plateau Physiographic Province. The Plateau Province contains the coalfields of Kentucky, Tennessee, Virginia, and West Virginia. Following a general discussion of groundwater within the overall Plateau Province, more specific information is provided for coalfield areas within each state where mountaintop mining may take place. Please refer to Table C-11, "Principal Aquifers of the Appalachian Plateau Province" which list the principal aquifers for each state and the correlating units across state boundaries.

Due to the large degree of lithologic variability of the bedrock within the coalfields, the USGS has utilized the geologic unit classification (e.g., group or formation name) as the basis for identifying the primary aquifers within the Plateau and associated coalfields within each state. As will be discussed below, most of the significant groundwater flow within the principal aquifers occurs within the fractured sandstone units within these formations or groups.

General Plateau Groundwater Occurrence and Quantity

Pennsylvanian-aged sandstone units are the most productive/widespread aquifers within Pennsylvanian-aged coal measures (USGS HA 730-K). Secondary porosity via rock fracturing is the primary means of movement of groundwater within the sandstone units since intergranular permeability is low (USGS HA 730-L); (refer to Figure C-1). Most fractures are shallow in depth, a few tens to a few hundreds of feet below ground surface, and decrease in number and openness with depth (USGS HA 730-L). Pennsylvanian-aged coals can also store and transmit water within their joint systems (USGS HA 730-L).

Harlow and LeCain (1993) found in studies completed in the coalfields of southwestern Virginia that the permeability of coal seams is greater than that for other rock types. At depths of less than 100 feet, though, Harlow and LeCain (1993) found that groundwater transmissivities (gal/day/ft or ft^2/day) were similar for coal seams, sandstone, and lithologic contacts. At depths of 200 feet only coal seams had consistently measurable permeability. Harlow and LeCain (1993) found that the mean depth to standing water below land surface measured from 43 uncased coreholes was 221 feet for hilltop locations, 109 feet for hillslopes, and 39 feet in valleys. Their studies indicate that groundwater flow is minimal below 300 feet depth due to increased overburden pressures and thus groundwater circulation is typically restricted to modest depths with discharge to valleys resulting either in stream flow or underflow beneath streams (Harlow and LeCain, 1993).

Table C-11
Principal Aquifers of the Appalachian Plateau Province *

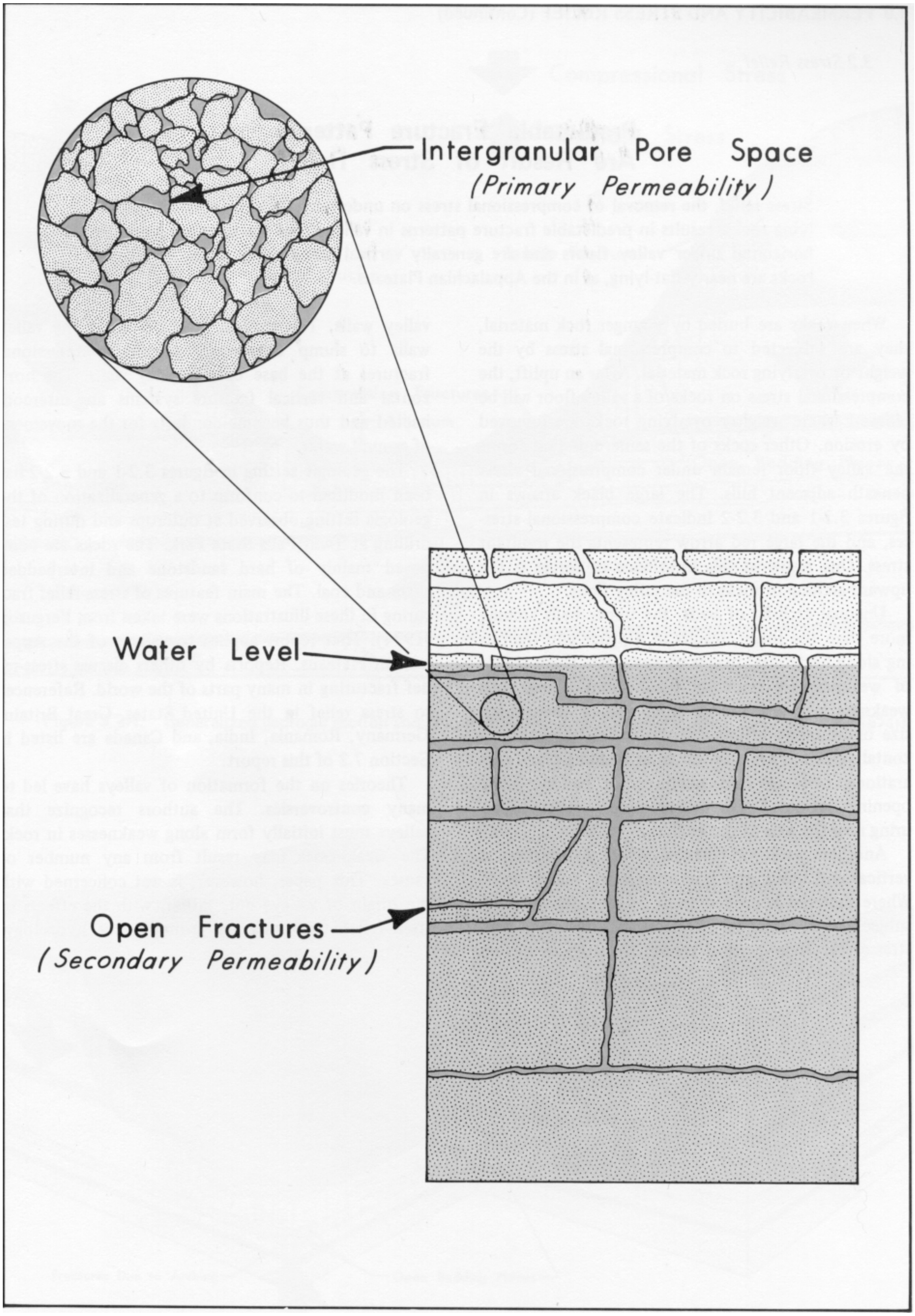
<table>
<tr><th>Geologic System</th><th>West Virginia</th><th>Virginia</th><th>Kentucky</th><th>Tennessee</th></tr>
<tr><td>Quaternary</td><td>Recent Valley Alluvium</td><td rowspan="5">Recent Valley Alluvium</td><td rowspan="2">Recent Valley Alluvium</td><td rowspan="4">Recent Valley Alluvium</td></tr>
<tr><td>Permian</td><td>Dunkard Group</td></tr>
<tr><td rowspan="2">Upper Pennsylvanian</td><td>Monongahela Group</td><td>Monongahela Group</td></tr>
<tr><td>Conemaugh Fm.</td><td>Conemaugh Fm.</td></tr>
<tr><td>Middle Pennsylvanian</td><td rowspan="2">Allegheny Group</td><td rowspan="3">Breathitt Formation</td><td>Cross Mt. Fm.
Vowell Mt. Fm.
Redoak Mt. Fm.
Graves Gap Fm.
Indian Bluff Fm.</td></tr>
<tr><td rowspan="2">Lower to Middle Pennsylvanian</td><td rowspan="2">Harlan Formation</td><td rowspan="2">Slatestone Formation
Crooked Fork Group</td></tr>
<tr><td rowspan="3">Pottsville Group

<u>Formerly</u> Kanawha
New River
Pocahontas
Formations</td></tr>
<tr><td rowspan="2">Lower Pennsylvanian</td><td rowspan="2">Wise Fm.
Gladeville SS
Norton Fm.
Lee Fm.</td><td rowspan="2">Lee Formation</td><td>Crab Orchard Mountains Group</td></tr>
<tr><td>Gizzard Group</td></tr>
<tr><td>Upper Mississippian</td><td>Mauch Chunk Group</td><td>Pennington Fm.</td><td>Pennington Fm.</td><td>Pennington Fm</td></tr>
<tr><td>Upper to Middle Mississippian</td><td>Greenbrier Limestone</td><td>Greenbrier Limestone</td><td>Newman Limestone</td><td>Newman Limestone</td></tr>
</table>

Shaded area indicates a hydrologic confining unit.

*Developed from USGS HA 730-L and HA 730-K, Harlow (1993), Cardwell (1968), and Rader (1993).

Figure C-1 Features of Primary and Secondary Permeability.



(Source: Wyrick and Borchers 1981)

Underlying Mississippian-aged limestones are more productive where they lie closer to the ground surface along the eastern and western fringes of the Appalachian coal basins, but within the central portions of the coal basin, in general, they lie quite deep below the Pennsylvanian- aged sandstones. Separating Pennsylvanian-aged sandstone from the main Mississippian limestone sequence are the Upper Mississippian Pennington/Mauch Chunck shales, which act as a relatively confining unit overlying the Mississippian limestones (Cardwell, 1968 and USGS HA 730-L).

Yields of the Pennsylvanian-aged sandstones range from 5-500 gpm; yield varies due to changes in lithology, thickness, and degree of development of secondary fracture zones (USGS HA 730-K and -L). Middle and Lower Pennsylvania Formations contain more sandstone units versus Upper Pennsylvanian units (USGS HA 730-K). Some sandstone units are regionally extensive and have well developed fracture systems and higher groundwater yields.

Groundwater recharge to bedrock aquifers within the Plateau Region is lower compared to the Valley and Ridge Province due to steeper slopes, thinner regolith (weathered rock/soil), and faster runoff characteristics of the Plateau Region (HA 730-L). Recharge occurs mainly at hilltops and side slopes and moves in a stepwise fashion vertically through fractures and then laterally through sandstone/coal beds, which are underlain by less permeable layers such as underclays or shales (USGS HA 730-L and -K).

Saline water may be near the ground surface within the Plateau region valley bottoms due to an upcoming effect caused by groundwater discharge in these areas Stoner, et al, 1987, Minns, 1995). In some areas of the Appalachian Plateau, regional movement of groundwater may not occur as models suggest due to the predominance of local and intermediate flow systems (USGS HA 730-L). Circulation of groundwater in the dissected Plateau behaves as hydrologic islands; the islands being separated by valley discharge zones or streams (USGS HA 730-L). Water moves down tributary valleys toward major rivers, partly as surface water flowing into and down the stream channel and partly as water discharging into the streams through alluvial deposits or permeable valley bottom bedrock aquifers (USGS HA 730-L). Springs commonly represent lateral flow intersections with valley sidewalls. This discharge from springs is generally from unconfined conditions. Water that leaks across low-permeability units can be present within permeable beds within synclinal troughs and confined flow and can become artesian flow when tapped by wells in valley bottom(USGS HA 730-L).

Saline water may exist at relatively shallow depths beneath larger stream valleys in the Appalachian region as models by Stoner, et al (1987) and Minns (1995) indicate.. Brine water sources may be from deeper rock units and may move up along deep fractures (USGS HA 730-L). It is likely that relatively flat-lying, confining units that impede vertical mixing of fresh and saline water, along with the lack of intense fracturing of rocks, as can be found within the Valley and Ridge Province, also limit mixing of fresh and saline groundwater within the Plateau region (USGS HA 730-L).

Although the sandstone bedrock units of the coal basins can, in some cases, be traced over many miles, the distribution of local aquifers within these formations depends mostly on the distribution of fractures and their permeability (USGS HA 730-L). Groundwater recharge tends to be concentrated along valley sidewalls (near vertical and horizontal tensile fractures related to valley slumping) and valley bottoms where near horizontal fractures, parallel to bedding, are present due to relief of compressional stresses via erosion over long time periods (USGS HA 730-L). Valley sidewall and bottom fractures are usually interconnected; fracturing tends to decrease toward ridge centers due to greater overburden pressure, and thus wells at ridge top settings will have lower yields (USGS HA 730-L). In general, well yields are directly proportional to the number of interconnected fractures (USG HA 730-L). Figure C-2, developed by Wyrick and Borchers (1981), provides a good representation of fracture patterns thought to occur within the Plateau bedrock and which exert a significant control on groundwater movement.

Underground mining can disturb the localized flow system by creating artificial drains, new fractures, and increased permeability, and can lower the groundwater table and/or change flow directions (USGS HA 730-L). Vertical fractures can connect deep mine areas with nearby wells, and existing deep mines may create “regional-like” flow patterns (USGS HA-730-L).

General Plateau Groundwater Quality

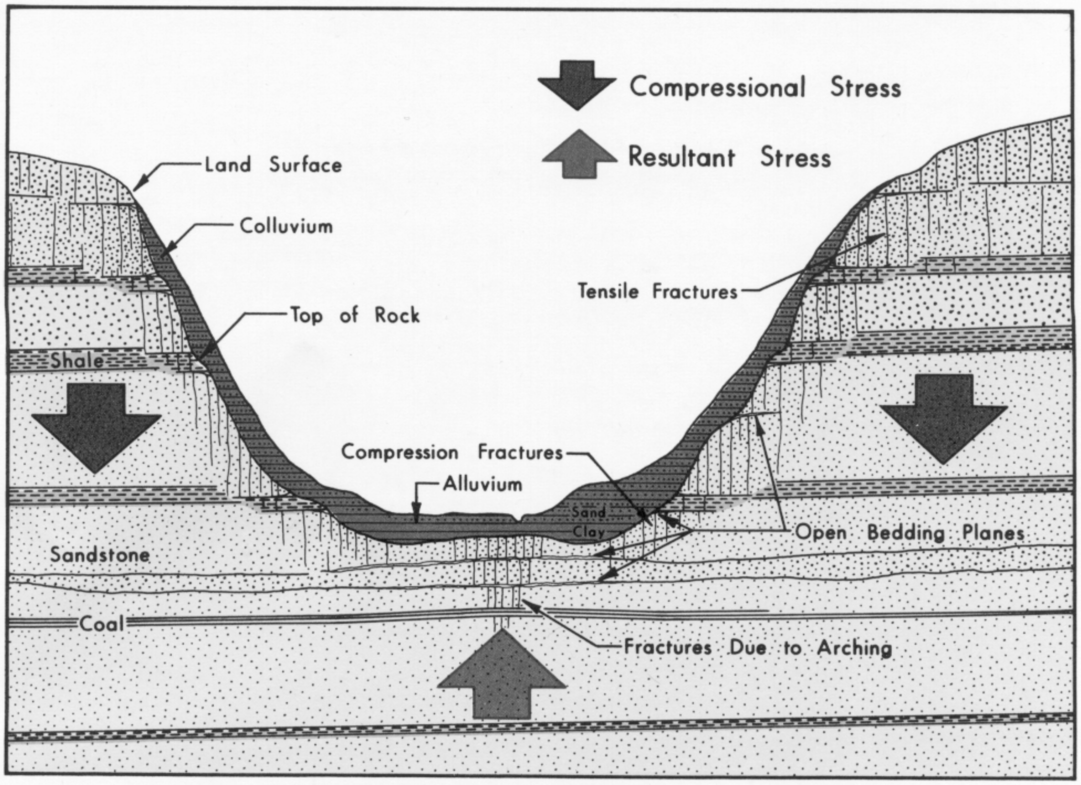
Within the plateau region, most fresh groundwater is of generally good quality, although some excessive levels of iron, chloride, and sulfate are known (USGS HA 730-K+L). Deeper groundwater is more mineralized than shallow waters due to greater residence time within the bedrock; saline water may be present within a few hundred feet of larger valley bottoms (HA-730-L+K). Water can be impacted by oil/gas development, brine solutions, waste disposal, and mining.

Most of the sedimentary rock minerals do not readily dissolve into groundwater, and thus dissolved solids of Plateau aquifers in undisturbed state have relatively low dissolved solids content, averaging about 230 mg/L (HA-730-L). Average hardness is about 95 mg/L (moderately hard; sandstone derived groundwater being softer versus shale derived groundwater), median pH is 7.3, and iron has a median concentration of 0.1 mg/L, with a high of 38 mg/L (HA-730-L). Plateau coalfield groundwater is of the sodium-bicarbonate or calcium-sodium bicarbonate (HA-730-L+K) type. Brine waters have dissolved solids concentrations of greater than 1000 mg/L and are found from 100 – 300 feet below larger valley bottoms although fresh water circulation may occur at very deep levels along deeply fractured or faulted zones (HA-730-L).

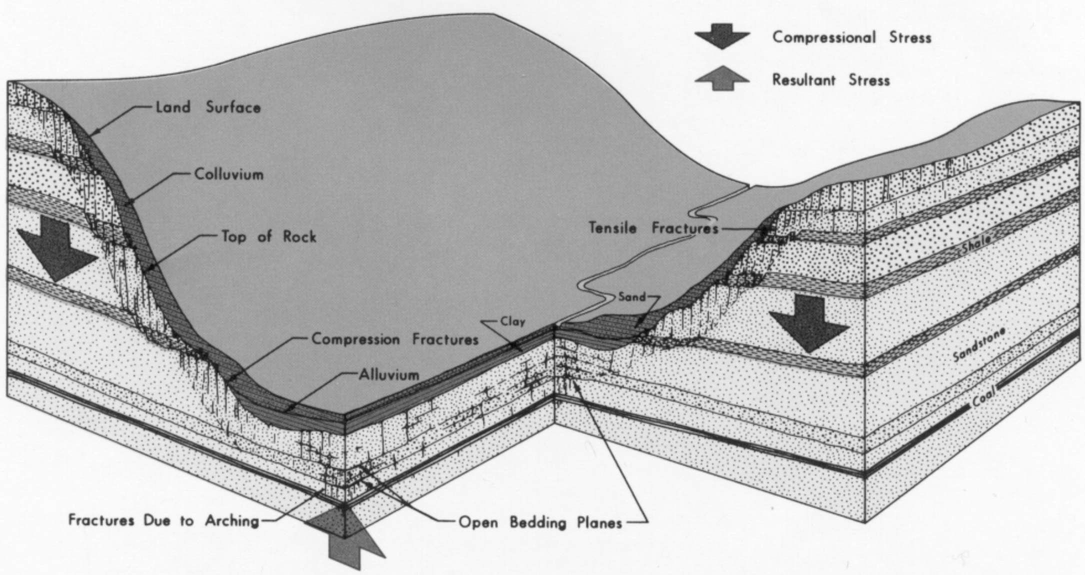
In surface mines, groundwater quality can be impacted by coal mining, with the greatest impact to uppermost aquifers and lessening impacts with depth (USGS HA 730-K). The basic chemical makeup of groundwater can change from a calcium bicarbonate type to a calcium sulfate type, along with increases in hardness, specific conductance, sulfate concentrations, and a decrease in pH. The chemical composition of coal and overburden also can have an impact on reclamation water quality (USGS 730-K and -L).

Total fresh groundwater withdrawals from consolidated sedimentary-rock aquifers in the Appalachian Plateau and Central Lowland Province is estimated at 282 mgd in 1985; 47 percent estimated for domestic/commercial uses and 41 percent for industrial, primarily mining related (HA-730-L). In the eastern Tennessee and Kentucky coal basins, surface water use greatly exceeds groundwater usage, exceeding 120 mgd for surface water to < 20 mgd for groundwater (USGS HA 730-K). Nevertheless, groundwater is still an important source of water for domestic, stock, small public, and industrial supplies (USGS HA 730-K).

Figure C-2 Stress-Relief Fracturing and Development of Secondary Permeability.



Generalized geologic section showing features of stress-relief fracturing



Block diagram of generalized geologic section showing features of stress-relief fracturing

(Source: Wyrick and Borchers 1981)

Kentucky Groundwater

Groundwater Occurrence and Quantity

Table C-11 presents the significant aquifers of the Plateau Province, which includes the coalfield provinces. As discussed earlier, groundwater flow within the aquifers is primarily within and through fractured/jointed sandstone bodies and also along bedding plane contacts. Within the Conemaugh, Breathitt and Lee Formations, multiple sandstone aquifers are present (Kiesler, 1983). Shale and coal yield some water, but less than the sandstone units.

In eastern Kentucky fresh groundwater yields for sandstones within the Breathitt and Conemaugh Formations range from 1 to 200 gpm, and those within the Lee Formation range from 1 to 300 gpm (Kiesler, 1983). Depths to water are usually less than 50 feet under valleys and about 300 feet under ridges (Kiesler, 1983). Wells less than 200 feet in depth usually yield 1-50 gpm and frequently are inadequate for domestic supply (Kiesler, 1983). Reportedly, wells greater that 300 feet in depth below perennial streams in the Lee Formation yield 300 gpm, and in the Breathitt Formation below 200 feet yield 200 gpm (Kiesler, 1983). These wells are possibly encountering upward-moving groundwater flow paths.

In the north and central portion of the coal province, yields of the Breathitt Formation are reported as ranging from <1 gpm up to 325 gpm; the Lee Formation from <1 gpm up to 140 gpm (Quinones, 1981). Groundwater yields obtained from sandstone beds at depths greater than 300 feet are probably from intergranular pore spaces due to likely sealing of fracture openings by overburden pressures (Quinones, 1981). Within the southern portion of Kentucky's Eastern Coal Province, groundwater yields of the Breathitt Formation are reported as ranging from 1-25 gpm and 1-250 gpm for the Lee Formation (Leist, 1982).

Groundwater Quality

Throughout the Plateau area of eastern Kentucky, groundwater quality is considered to be generally suitable (Kiesler, 1983, Quinones, 1981, and Leist, 1982). In eastern Kentucky groundwater ranges from soft to hard, with iron being the most objectionable constituent; ranging from 100-157,000 ug/L (Kiesler, 1983). Saline water (>1000 mg/L total dissolved solids) is usually found at 100 feet below principal valley bottoms, but also first encountered at depths of 300 feet (Kiesler, 1983). Saline or brine waters are common in oil/gas areas due to brine migration up wells with improperly installed well casings (Kiesler, 1983). Brines with more than 35,000 mg/l are known to occur at depth (Kiesler, 1983). Table C-12 below summarizes 1980 water quality data for the Lee and Breathitt Formation aquifers in eastern Kentucky (Kiesler, 1983).

Groundwater within the northern and central section of Kentucky's Eastern Coal Province is also considered to be generally suitable with iron again the most objectionable constituent ranging from 0.01 to 800 mg/L (Quinones, 1981). The source of this iron is likely related to coal mining activity (Quinones, 1981). Hardness ranges from 4 to 866 mg/L, and groundwater can be one of three types: calcium-magnesium bicarbonate, sodium bicarbonate, or sodium sulfate none of which is unique to the Breathitt or Lee Formations (Quinones, 1981). Table C-13 below provides a summary of groundwater quality for the Breathitt and Lee Formations (Quinones, 1981).

Within the southern portion of the eastern coalfields, groundwater quality is similar to the rest of the coalfield area except for apparently lower dissolved iron contents in the groundwater, ranging from 0.003 to 25 mg/L (Leist, 1982). Hardness ranges from 5-790 mg/L as reported in Table C-14 below (Leist, 1982). Saline or brine (>35,000 mg/L total dissolved solids) water are reported to occur at less than 100 feet below the deepest valley bottoms (Leist, 1982).

Table C-12
General Groundwater Composition of the Eastern Kentucky Coalbasin (Kiesler, 1983)

	Constituent (mg/L)	Range	Median	Number of Samples
CONEMAUGH-BREATHITT FORMATIONS	Iron (Fe)	0.01 - 157	1.0	100
	Calcium (Ca)	2.4 - 248	27	118
	Magnesium (Mg)	0.5 - 177	7.5	117
	Sodium (Na)	1.5 - 742	29	121
	Potassium (K)	0.5 - 22	2.4	116
	Bicarbonate (HCO_3)	0 - 537	153	102
	Sulfate (SO_4)	0.1 - 2,749	13	185
	Chloride (Cl^-)	1 - 2,450	11	238
	Specific conductance (Microhms per centimeter at 25˚C)	60 - 7,620	378	183
	Hardness as calcium carbonate ($CaCO_3$)	3 - 2,190	96	185
	pH (Units)	2.6 - 8.8	7.1	167

	Constituent	Range	Median	Number of Samples
LEE FORMATION	Iron (Fe)	0.01 - 16	0.82	25
	Calcium (Ca)	1.3 - 150	22	155
	Magnesium (Mg)	0.40 - 57	6.5	155
	Sodium (Na)	1.4 - 400	27	153
	Potassium (K)	0.8 - 9.2	1.9	153
	Bicarbonate (HCO_3)	10 - 388	226	25
	Sulfate (SO_4)	0 - 610	12	174
	Chloride (Cl^-)	1.0 - 849	9.4	177
	Specific conductance (Microhms per centimeter at 25˚C)	39 - 2,970	310	175
	Hardness as calcium carbonate ($CaCO_3$)	5 - 580	85	174
	pH (Units)	5.5 - 9.0	7.0	173

Table C-12
General Groundwater Composition of the Eastern Kentucky Coalbasin (Kiesler, 1983)

	Constituent	Range	Median	Number of Samples
MISSISSIPPIAN-DEVONIAN ROCKS	Iron (Fe)	- - -	-	0
	Calcium (Ca)	0.4 - 68	46	18
	Magnesium (Mg)	0.10 - 38	8.9	18
	Sodium (Na)	2.8 - 310	16	18
	Potassium (K)	0.1 - 2.1	1.0	18
	Bicarbonate (HCO_3)	- - -	-	0
	Sulfate (SO_4)	1.6 - 120	28	18
	Chloride (Cl)	2.2 - 210	8.3	18
	Specific conductance (Microhms per centimeter at 25˚C)	270 - 1,470	330	18
	Hardness as calcium carbonate ($CaCO_3$)	1 - 320	145	18
	pH (Units)	6.7 - 8.1	7.7	18

Table C-13
General Groundwater Composition for
Northern and Central Kentucky Coalbasin (Quinones, 1981)

	Constituent	Range			Median	Number of Samples
BREATHITT FORMATION	Iron (Fe)	0.01	-	890	0.73	188
	Calcium (Ca)	1.4	-	124	32	29
	Magnesium (Mg)	.9	-	41	10	29
	Sodium (Na)	.6	-	318	83	26
	Potassium (K)	1.0	-	9.4	3	25
	Bicarbonate (HCO_3)	0.0	-	620	138	189
	Sulfate (SO_4)	0.0	-	1,100	22	189
	Chloride (Cl)	.8	-	1,200	10	240
	Specific conductance (Microhms per centimeter at 25°C)	22	-	4,530	388	189
	Hardness as calcium carbonate ($CaCO_3$)	4	-	886	96	189
	pH (Units)	3.5	-	9.7	6.9	183
LEE FORMATION	Iron (Fe)	0.01	-	6.4	0.23	40
	Calcium (Ca)	3.6	-	52	5.5	28
	Magnesium (Mg)	.2	-	24	1.4	28
	Sodium (Na)	2.3	-	317	247	27
	Potassium (K)	1.1	-	28	2.2	27
	Bicarbonate (HCO_3)	14	-	512	267	50
	Sulfate (SO_4)	0.0	-	65	4.0	51
	Chloride (Cl)	.5	-	2,050	44	74
	Specific conductance	40	-	1,620	809	50
	Hardness as Calcium Carbonate ($CaCO_3$)	7	-	256	27	51
	pH	6.0	-	8.9	7.5	46

Table C-13
General Groundwater Composition for
Northern and Central Kentucky Coalbasin (Quinones, 1981)

	Constituent	Range	Median	Number of Samples
PRE-PENNSYLVANIAN ROCKS	Iron (Fe)	0.01 - 14	0.4	10
	Calcium (Ca)	13 - 14	-	2
	Magnesium (Mg)	1.0 - 1.2	-	2
	Sodium (Na)	.8 - 1.0	-	2
	Potassium (K)	.07 - 1.2	-	2
	Bicarbonate (HCO_3)	9 - 442	122	10
	Sulfate (SO_4)	1.4 - 260	7.0	11
	Chloride (Cl)	1.0 - 134	5	11
	Specific conductance	52 - 55	-	2
	Hardness as Calcium Carbonate ($CaCO_3$)	32 - 272	82	9
	pH	6.0 - 7.5	7.1	6

Table C-14
General Groundwater Composition for Southern Kentucky Coalbasin (Leist, 1982)

	Constituent (mg/L)	Range			Median	Number of Samples
BREATHITT FORMATION	Iron (Fe)	0.02	-	25	1.0	98
	Calcium (Ca)	2.3	-	86	26	15
	Magnesium (Mg)	0.5	-	38	6.4	15
	Sodium (Na)	1.2	-	312	22	15
	Potassium (K)	0.3	-	6.4	2.2	14
	Bicarbonate (HCO_3)	0	-	455	127	99
	Sulfate (SO_4)	0	-	237	9.7	98
	Chloride (C1)	0.5	-	220	4	120
	Specific conductance (Microhms per centimeter at 25°C)	17	-	1,410	215	98
	Hardness as calcium carbonate ($CaCO_3$)	5	-	540	82	99
	pH (Units)	3.8	-	9.7	6.9	95
	Dissolved solids	16		798	199	11
LEE FORMATION	Iron (Fe)	0.003	-	9.7	0.79	49
	Calcium (Ca)	1	-	201	13	36
	Magnesium (Mg)	0.30	-	70	2.5	41
	Sodium (Na)	0.4	-	1,520	1.8	38
	Potassium (K)	0.5	-	19	4.6	38
	Bicarbonate (HCO_3)	5	-	315	61	61
	Sulfate (SO_4)	0	-	240	6.5	64
	Chloride (C1)	0	-	2,630	3	89
	Specific conductance (Microhms per centimeter at 25°C)	15	-	8,240	137	63
	Hardness as calcium carbonate ($CaCO_3$)	5	-	790	44	63
	pH (Units)	5.7	-	8.4	6.8	59
	Dissolved solids	19		4,860	77	36

Tennessee Groundwater

Groundwater Occurrence and Quantity

Within the northern Tennessee coal basin, well yields in the Pennsylvanian aquifers range from <5 to >300 gpm, with 62 percent of 376 wells having yields ranging from 10 to 25 gpm (Gaydos, 1982). As in other areas of the Plateau, groundwater occurs primarily within fractures and joints of sandstone units of Pennsylvanian-aged rocks. Variation in yields and transmissivities is due to the difference in the size and the irregular nature of the fracture system in Pennsylvanian units. Most of all wells are less than 400 feet in depth and most of all domestic wells are less than 200 feet in depth (Gaydos, 1982). Transmissivities of wells range from 5 - 13,000 ft^2/day, with 68 percent of all wells ranging from 11 - 240 ft^2/day (Gaydos, 1982).

Within the central portion of the Eastern Tennessee Coal Basin, well yields for wells completed in Pennsylvanian aquifers range from 5-150 gpm. Transmissivities estimated from specific capacity data for 16 wells and range from 20-2,000 ft^2/day, 68 percent of which range from 30-500 ft^2/day (Gaydos, 1982). This wide range is primarily due to variation in size and extent of the fracturing in the sandstones of the Pennsylvanian rock units (Gaydos, 1982).

In the southern section of the coal basin, groundwater flow, as for other areas in the Appalachian Plateau's coal basins, is primarily through fractured/jointed sandstone bodies which have intergranular permeability (Hollyday, 1983). Most water zones are within 100 feet of ground surface (Hollyday, 1983). For more than 400 wells, measured yields ranged from <5 gpm to about 300 gpm, with 68 percent of the wells being less than 20 gpm (Hollyday, 1983). Estimated transmissivities for 6 wells range from 20-75 ft^2/day, with 68 percent of the wells ranging from 30-700 ft^2/day (Hollyday, 1983).

Groundwater Quality

Within the northern areas of the coal basin, iron and chloride levels are relatively high in groundwaters, with chlorine being more common at depth due to brine water contaminating overlying fresh groundwater (Gaydos, 1982). Pennsylvanian aquifers within this area generally need minimal treatment for use and are moderately mineralized, slightly acidic, and soft to moderately hard (Gaydos, 1982). Table C-15 below provides some general water quality data for undifferentiated Pennsylvanian rocks in the northern section of the coal basin (Gaydos, 1982).

Within the central portion of Tennessee's Eastern Coal Field, groundwater is of suitable quality, generally soft to moderately hard, and is of a calcium bicarbonate, sodium bicarbonate, or calcium sulfate type (Gaydos, 1982). Dissolved solids are relatively low, with some sandstone aquifers reporting low pH and high manganese concentrations (Gaydos, 1982). Excessive iron levels are a major problem in Cumberland County.

Within the southern portion of the coalfields, groundwater is again considered to be of generally good quality, ranging from soft to moderately hard (Hollyday, 1983). Groundwater, as in other areas of the coal basin, is either a calcium bicarbonate, sodium bicarbonate, or calcium sulfate type with dissolved solids concentrations low, and locally high concentrations of iron and manganese. Table C-16 below, obtained from Hollyday (1983), provides some water quality data for wells completed with the Pennsylvanian-aged aquifers. Data collected from wells at sites 7, 14, 15, 17, 23-25, 28, 31-33, and 35 are for Plateau aquifer units.

Table C-15
General Groundwater Composition for Northern Tennessee Coalbasin

AQUIFER	Aquifer Type	Hardness (milligrams per liter)	Iron (micrograms per liter)	Sulfate (milligrams per liter)	Chloride (milligrams per liter)	Dissolved Solids (milligrams per liter)	pH (Units)
Pennsylvanian rocks (undifferentiated)	Fractured sandstone and conglomerate	40-120	400-6,000	5-60	5-50	250-400	6.4-7.2
Mississippian rocks (undifferentiated)	Carbonate rocks	100-300	100-1,000	1-100	1-20	150-400	6.8-7.8
Ordovician rocks (undifferentiated)	Limestone	200-400	100-2,000	5-50	2-50	250-500	6.8-8.0

(Numerical ranges represent typical values and do not include unusually high or low values)

Table C-16
General Groundwater Composition for Northern Tennessee Coalbasin (Hollyday, 1983)

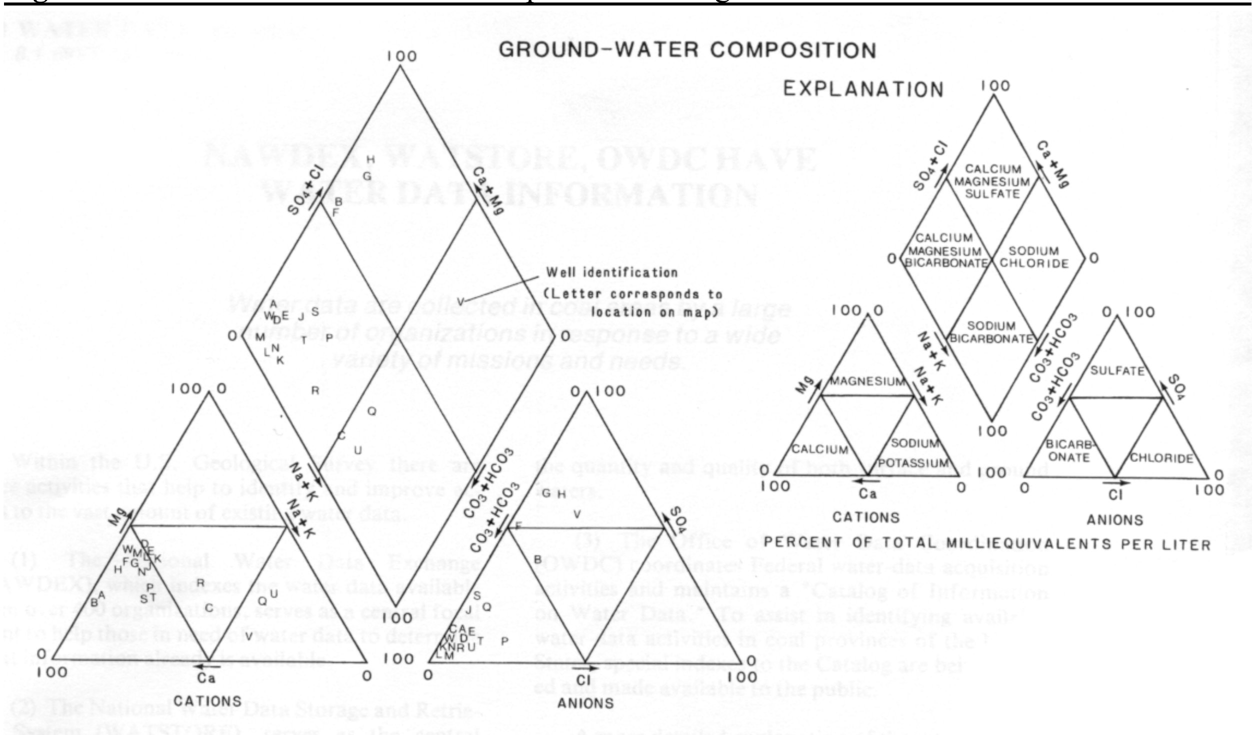
Site Number	Year Sampled	Specific Conductance (µmho/cm)	Dissolved solids, residue at 180°C (mg/L)	pH (units)	Dissolved Iron (µg/L)	Dissolved Manganese (µg/L)	Dissolved sulfate (mg/L)	Hardness as $CaCO_3$ (mg/L)
1	1960	128	106	6.7	-	-	4.0	-
2	1960	668	517	7.4	30	-	215.	370
3	1965	262	-	7.9	-	-	.4	140
4	1963	41	40	6.5	-	-	.0	8
5	1970	227	156	7.6	-	10	.0	-
6	1960	166	117	7.2	10	-	.4	84
7	1958	55	39	6.0	1,300	-	3.4	16
8	1958	275	160	7.4	490	-	18	140
9	1963	300	212	7.6	-	-	4.4	150
10	1958	365	213	7.6	20	-	6.2	190
11	1946	-	124	-	-	-	5.8	-
12	1946	-	7,280	-	-	-	206	-
14	1976	30	43	5.2	2,400	270	1.5	6
15	1976	138	128	6.4	960	1,200	.8	75
16	1958	289	163	7.7	120	-	4.8	150
17	1958	78	60	6.7	11,000	1,000	1.7	12
18	1977	200	126	7.4	10	0	10	91
19	1975	205	-	7.2	-	-	1.5	100
21	1974	140	-	7.4	-	-	-	68
22	1974	189	-	7.4	-	-	1.9	-
23	1954	135	77	6.8	-	-	14	54
24	1954	201	110	7.2	-	-	10	98
25	1954	180	102	6.9	-	-	3.0	90
26	1977	290	144	7.5	10	10	2.3	130
27	1977	180	118	7.9	40	0	3.0	97
28	1977	180	97	7.1	290	90	1.7	61
29	1954	-	62	6.6	-	0	3.0	34
30	1977	580	-	7.5	50	10	22	250
31	1977	250	144	7.5	30	310	5.2	84
32	1954	202	124	6.8	-	-	17	68
33	1977	225	115	7.4	0	0	7.3	100
34	1977	250	-	7.6	10	10	3.5	120
35	1977	280	160	7.8	0	10	3.1	120
Range		30-668	39-7,280	5.2-7.9	0-11,000	0-1,200	.0-215	6-370
Median		202	124	7.4	35	10	3.5	98
No. of Samples		30	27	31	18	14	32	28

5

Virginia Groundwater

Groundwater Occurrence and Quantity

Figure C-3 General Ground-Water Composition of Virginia Coal Fields.



Within the Appalachian Plateau coalfields of Virginia, groundwater occurs primarily within and is obtained from fractured sandstone bedrock. Groundwater moves and is stored primarily along bedding planes and within jointing and fracture systems within the rocks and is the major source of water for many domestic, commercial, and public supplies (Hufschmidt, 1981). Per Hufschmidt (1981), well yields range from 5 to 200 gallons per minute, with most less than 30 gallons per minute, and vary depending upon the type of rock and the number and size of openings penetrated by the well within the rock unit.

Groundwater Quality

Per Hufschmidt (1981), groundwater quality is highly variable but generally suitable for most uses within the coalfield province of Virginia. Groundwater from Pennsylvanian-aged sandstone is characteristically of the calcium magnesium sulfate type with hardness varying considerably (Hufschmidt, 1981). As for other areas within the Allegheny Plateau coalfields, water quality within the Virginia coalfields can be impacted by many factors including rock type, duration of water contact with bedrock, and external sources of contamination. Within the Virginia coalfields, dissolved solids concentrations are generally low, but locally high concentrations of iron, sulfate, and hardness can occur and, in some areas, high levels of chloride and nitrate suggest contamination by septic systems (Hufschmidt, 1981). Per Hufschmidt (1981) wells constructed deeper than 200 to 300 feet below land surface and located near major rivers may encounter slightly to moderately saline water. Figure C-3 depicts general groundwater composition of Virginia coal fields.

(Source: USGS 1981)

West Virginia Groundwater

Groundwater Occurrence and Quantity

As for other regions of the plateau, sandstone units within West Virginia coal basin geologic formations and groups are the most productive aquifers within the coal basins of the Appalachian Plateau (see Table C-11). Yields from sandstones for these units throughout the Plateau region of West Virginia range from 5 to 400 gpm (USGS HA 730-L). Groundwater movement is largely by secondary permeability via bedrock fractures, joint systems, and bedding planes, and groundwater yields can be highly variable depending whether or not these features are encountered (Ehlke, 1982). Within the majority of the West Virginia's Plateau coalfields, i.e., mostly central/ south-central West Virginia, alluvial deposits along the larger rivers serve as productive sources of groundwater due in part to their adequate thicknesses (Ehlke, 1982).

Table V.C.1.-7 (Ehlke, 1982, 5.0.1) provides specific data for 53 wells in the central/south-central region of West Virginia, i.e. the Plateau region. These data show groundwater well yields, expressed in terms of specific capacity range, from <0.1 to 100 gal/min per foot of water-level drawdown within the well (Ehlke, 1982). Wells that encountered very few fractures, joints, or bedding plane partings usually have a specific capacity of equal or less than 1.0 gal/min per foot of well drawdown.

Within the southwestern portion of the Plateau fractured sandstone also provides the most significant source of groundwater, while alluvium is less productive compared to the central/south-central areas of the Plateau's coal basins due to its thinner nature (Ehlke, 1982). In the southwestern Plateau region of West Virginia, average yields from wells in valleys is reported to be 27 gal/min., and 9 gal./min. for wells within upland areas (Ehlke, 1982). Overall yields for all wells within the Plateau's Pennsylvanian sandstone and Quaternary alluvial aquifers ranges from 0.5 to 340 gal./min. (Ehlke, 1982). As discussed in the groundwater introductory section above, some groundwater occurring within the alluvium is flow-through contributed by discharges into the alluvium from the underlying fractured bedrock.

Groundwater Quality

Table C-18 (Ehlke, 1982) below provides comparative water quality data for southwestern West Virginia wells placed in alluvium and Upper and Lower Pennsylvanian aquifer units, in addition to summary water quality data for Upper and Lower Pennsylvanian aquifers unaffected by saltwater intrusion and mining, and for wells affected by these two activities. Also included are some typical chemical analyses for three wells not affected by mining or saltwater intrusion and located within Upper and Lower Pennsylvanian and alluvial aquifers (Ehlke, 1982). Wells 1401 and 5401 are located in Cabell County, and well 2701 is located in northern Logan County (Ehlke, 1982).

These data reveal that groundwater quality appears to be best in alluvial aquifers, at least in southwestern West Virginia. These aquifers have the lowest specific conductivity, pH, alkalinity, hardness, and chloride, iron, and manganese concentrations (Ehlke, 1982). Well sample data from Upper Pennsylvania aquifers have the highest values. Upper Pennsylvanian rock units are more soluble versus the other units and also contain more limestone than either, resulting in higher values for specific conductance, alkalinity, calcium, carbonate hardness, and dissolved solids (Ehlke, 1982). A concern in areas of deep mines, such as southwestern West Virginia, is that groundwater leaking from deep mines can impact other groundwater zones, increasing sulfate and noncarbonate hardness and also increasing dissolved solids in streams following discharge from the mines (Ehlke, 1982).

Table C-17
General Groundwater Composition of Virginia Coalfields
(Hufschmidt, 1981)

Well Number	Latitude	Longitude	County	Specific Capacity (gal/min)
1	38 34 49	80 42 34	Braxton	10.0
2	38 36 56	80 54 41	Braxton	.83
3	38 40 25	80 48 22	Braxton	8.0
4	38 40 43	80 35 27	Braxton	3.0
5	38 41 33	80 48 55	Braxton	2.0
6	38 20 46	81 09 47	Clay	2.5
7	38 27 39	80 51 51	Clay	25.
8	38 27 47	80 51 41	Clay	100.
9	38 30 50	80 46 17	Nicholas	.33
10	38 31 01	80 46 59	Nicholas	2.33
11	38 21 01	81 38 56	Kanawha	1.71
12	38 21 01	81 38 05	Kanawha	2.0
13	38 21 43	81 38 56	Kanawha	52.
14	38 22 11	81 34 28	Kanawha	25.
15	38 26 19	81 33 14	Kanawha	.07
16	37 51 00	81 48 27	Logan	.14
17	37 51 02	81 48 28	Logan	.20
18	37 52 19	81 50 18	Logan	.006
19	37 52 56	81 48 04	Logan	4.8
20	37 53 21	81 49 23	Logan	11.2
21	38 08 32	81 56 51	Lincoln	.012
22	38 09 15	81 56 52	Lincoln	.06
23	38 12 44	81 53 56	Lincoln	.18
24	38 13 43	81 53 30	Lincoln	.10
25	38 14 23	81 52 10	Lincoln	.04
26	38 15 29	81 48 41	Lincoln	.14
27	38 18 44	81 52 31	Lincoln	.04
28	38 12 01	81 44 29	Kanawha	.36
29	38 13 37	81 45 50	Kanawha	.04
30	38 17 33	81 46 49	Kanawha	.24
31	38 18 58	81 52 29	Kanawha	.82
32	38 21 01	81 53 13	Kanawha	.12
33	38 24 10	81 52 14	Kanawha	.12
34	37 48 06	81 35 38	Boone	2.0
35	37 53 40	81 40 20	Boone	.20
36	37 55 25	81 40 51	Boone	.04
37	37 57 20	81 52 55	Boone	.12
38	37 59 24	81 44 17	Boone	.24
39	38 04 28	81 36 29	Boone	.28

Table C-17
(Continued)

40	38 06 04	81 34 12	Boone	.32
41	38 07 36	81 35 14	Boone	.26
42	38 08 30	81 51 22	Boone	.40
43	38 07 57	81 48 54	Boone	.04
44	37 43 43	81 16 52	Raleigh	8.4
45	37 46 14	81 18 30	Raleigh	.62
46	37 49 15	81 28 27	Raleigh	4.8
47	37 51 34	81 25 02	Raleigh	5.0
48	37 52 30	81 30 48	Raleigh	1.0
49	37 56 21	81 21 13	Raleigh	.12
50	37 57 10	80 31 15	Raleigh	2.2
51	37 54 57	80 40 53	Greenbrier	2.0
52	37 59 05	80 42 59	Greenbrier	1.0
53	37 52 39	80 47 58	Fayette	5.4

Table C-18
Specific Capacity Data for Selected Wells in Central/Southcentral West Virginia
(Source: Ehlke 1982)

		Comparison of Water Analyses from Wells Unaffected by Mining or Salt Water.										
		Specific Conductance (µmhos/cm)	**pH (units)**	**Alkalinity (mg/L)**	**Chloride (mg/L)**	**Sulfate (mg/L)**	**Hardness as $CaCO_3$ (mg/L)**	**Hardness non-Carbonate (mg/L)**	**Dissolved Solids (sum) (mg/L)**	**Dissolved Iron (µg/L)**	**Dissolved Manganese (µg/L)**	**No. of Wells**
Alluvium	Max	710	7.3	246	29	110	200	110	433	170	60	14
	Min	100	5.5 *	12	0	11	26	0	55	0	0	
	Mean	224	6.6	57	8.7	38	77	23	136	100	19	
Upper	Max	1,000	8.9	435	120	100	300	53	646	32,000	3,900	94
Pennsylvania	Min	100	6.2 *	0	1.0	0.1	3	0	119	0	0	
	Mean	499	7.2	229	19	21	109	3.7	318	1,686	274	
Lower	Max	930	8.3	435	180	88	230	75	588	16,000	8,900	191
Pennsylvania	Min	45	4.5 *	9	0.8	0	3	0	21	10	0	
	Mean	269	7.0	94	14	34	68	6.5	152	3,266	232	
*Median Value												

Table C-18
(Continued)

Summary of Water Analyses from Wells in the Upper Pennsylvania System.

		Specific Conductance (µmhos/cm)	pH (units)	Alkalinity (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Hardness as $CaCO_3$ (mg/L)	Hardness non-Carbonate (mg/L)	Dissolved Solids (sum) (mg/L)	Dissolved Iron (µg/L)	Dissolved Manganese (µg/L)	No. of Wells
	Max	1,000	8.9	435	120	100	300	53	646	32,000	3,900	94
	Min	1,750	7.4	328	78	870	950	670	1,520	7,100	640	7
	Mean	5,500	8.4	361	2,200	28	1,900	1,900	3,420	77,000	1,400	7
Wells unaffected by mining or salt water	Max	100	6.2	0	1.0	0.1	3	0	119	0	0	94
	Min	300	6.1	68	0.8	60	130	57	200	20	10	7
	Mean	850	7.2	0	100	0.4	6	0	529	30	0	7
	Max	499	7.2*	229	19.2	20.9	109	3.7	318	1,690	274	94
*Median Value	Min	1,000	7.2*	207	19	353	496	290	746	1,400	196	7
	Mean	2,150	7.9*	235	643	11	397	313	1,300	13,360	280	7

Table C-18
(Continued)

Summary of Water analyses from wells in the Lower Pennsylvania System (Pottsville).

		Specific Conductance (µmhos/cm)	pH (units)	Alkalinity (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Hardness as $CaCO_3$ (mg/L)	Hardness non-Carbonate (mg/L)	Dissolved Solids (sum) mg/L)	Dissolved Iron (µg/L)	Dissolved Manganese (µg/L)	No. of Wells
	Max	930	8.3	435	180	88	230	75	588	16,000	9,900	191
	Min	2000	8.0	130	250	1,200	1,300	1,300	1,790	180,000	9,900	38
	Mean	3500	7.6	254	1,000	3.1	210	38	1,930	9,800	650	10
Wells unaffected by mining or salt water	**Max**	45	4.5	9	0.8	0	3	0	21	10	0	191
	Min	70	4.1	0	1.0	0.4	24	13	42	0	0	38
	Mean	650	6.7	123	140	0	32	0	385	60	10	10
* Median value	**Max**	269	7.0*	94	14	34	68	6.5	152	3,270	232	191
	Min	482	6.6*	32	19	172	183	150	324	16,500	4,230	38
	Mean	1,250	7.2*	174	304	1.2	100	3.8	696	2,587	196	10

Table C-18
(Continued)

“Typical” chemical analyses from wells not affected by mining or salt-water intrusion in the three major geologic units.																
Geologic Unit	**Well No.**	**Date Sampled**	**Temp. (0°)**	**Specific Conductance (µmhos/cm)**	**pH (units)**	**Alkalinity (mg/L)**	**Ca (mg/L)**	**Mg (mg/L)**	**Na (mg/L)**	**Cl^- (mg/L)**	**SO_4 (mg/L)**	**Hard-ness as $CaCO_3$ (mg/L)**	**Hard-ness non-Carbonate (mg/L)**	**Dis-solved solids (mg/L)**	**Dis-solved Iron (µg/L)**	**Dis-solved Manga-nese (µg/L)**
Alluvium 382635082041401		03-24-76	14.0	235	6.6	36	25	6.6	8.5	12	29	90	54	115	30	10
UPPER PENNSYLVANIAN 382310082135401		04-21-76	16.0	500	7.1	203	49	11	43	6.8	53	170	0	307	2,500	520
LOWER PENNSYLVANIAN 380200081572701		05-04-77	16.0	230	7.1	78	25	5.0	8.0	2.3	15	83	5	122	2,600	220

Table C-19
Comparative Groundwater Quality Data for Southwestern West Virginia (Ehlke, 1982)

Geohydrologic Unit	Hardness	Dissolved Solids	Bicarbonate	Chloride	Sulfate
10	88	204	107	27	38
11	148	424	288	65	40
12	80	141	72	9	39

Notes:
Unit 10 = Allegheny and Pottsville Group Aquifers Combined
Unit 11 = Monongahela Group and Conemaugh Formation Aquifers Combined
Unit 12 = Alluvial Aquifers
Average hardness and concentration of dissolved solids, bicarbonate, chloride, and sulfate in mg/L of groundwater in the Guyandotte River basin.

Taken from Schwietering, J.F., "Brief Description of Ground-Water Conditions and Aquifers in West Virginia", Table 4, published by WV Dept. of Natural Resources Open-File Report OF 8102, January, 1981.